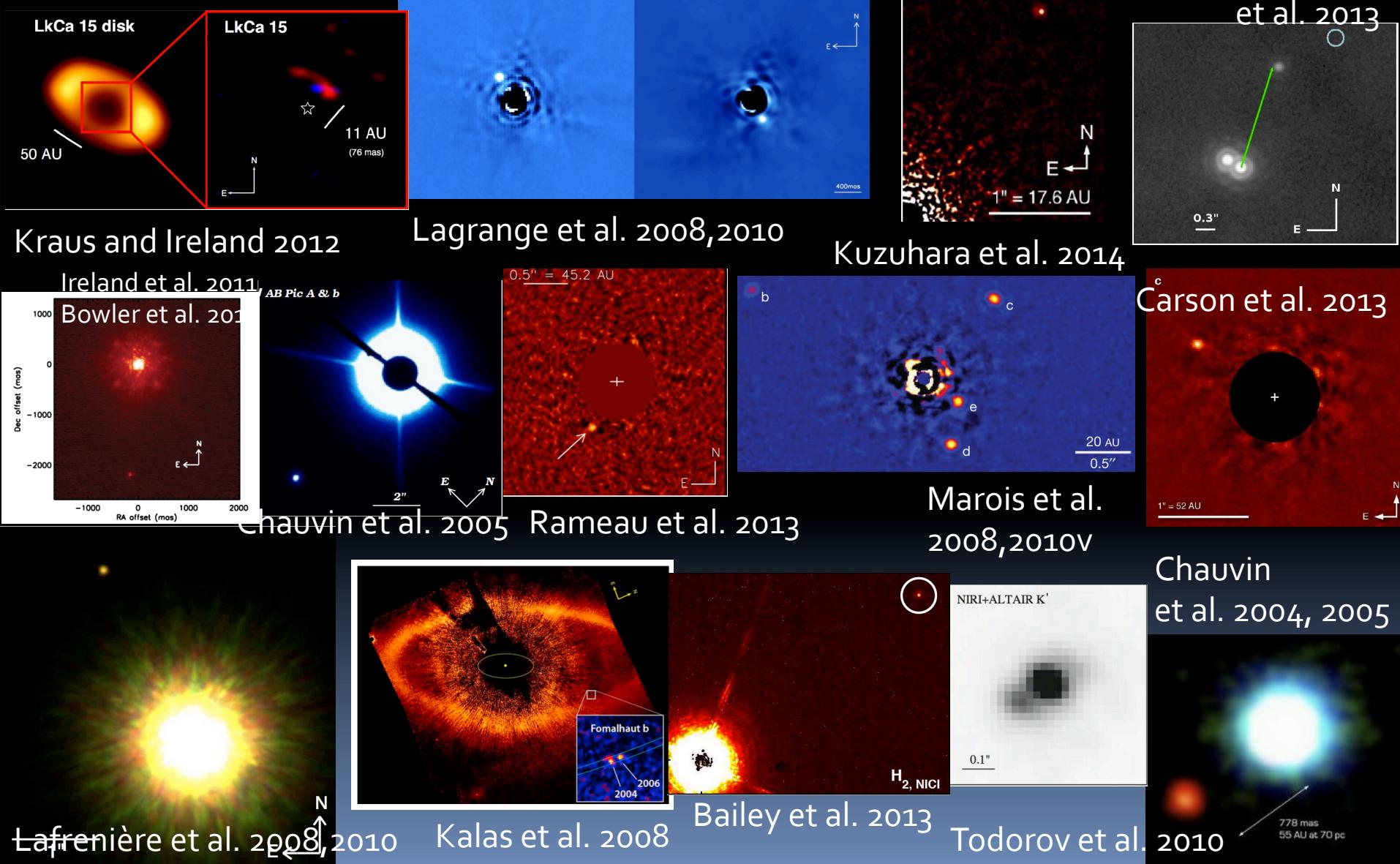
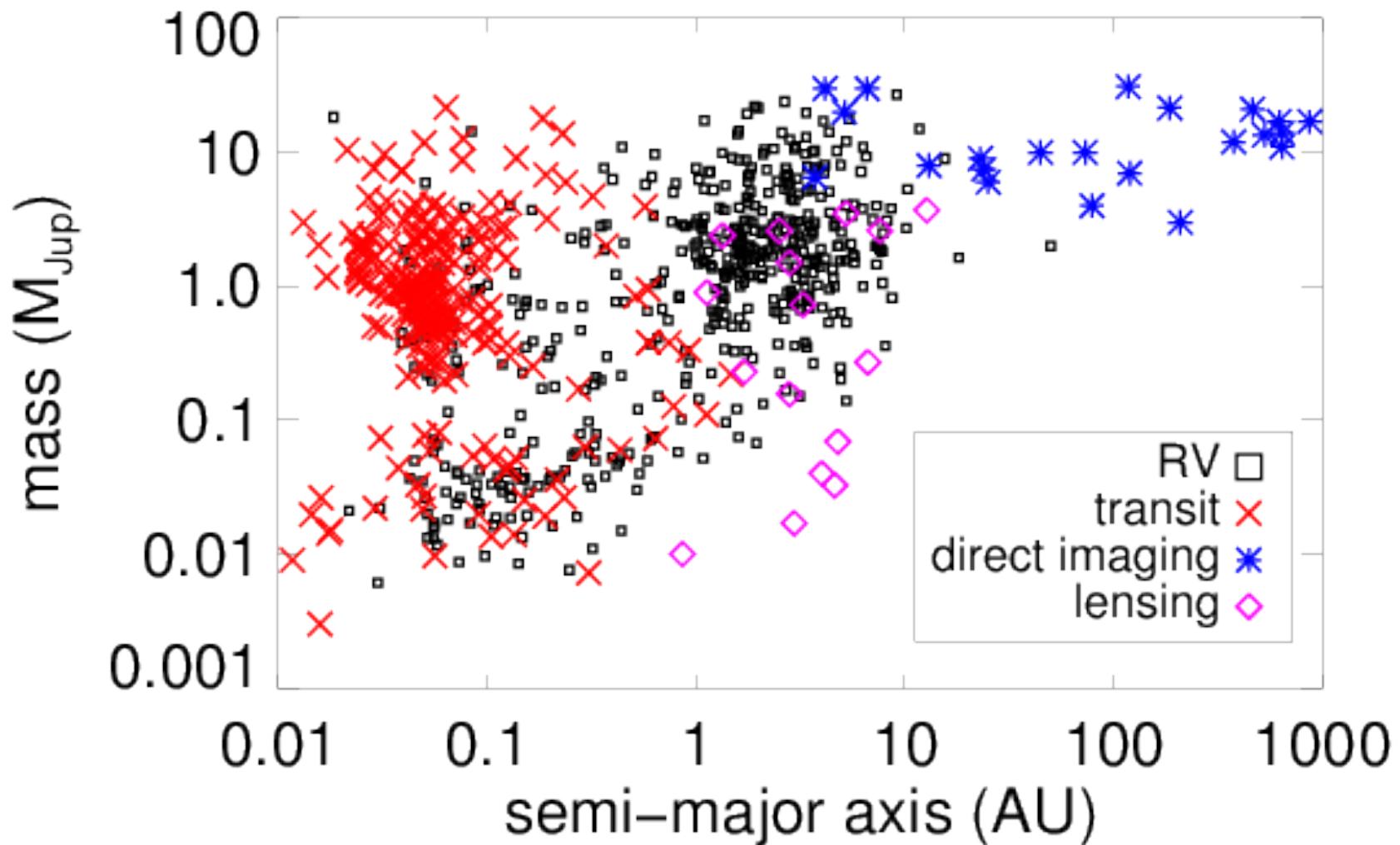


# DETECTING AND CHARACTERIZING EXOPLANETS VIA DIRECT IMAGING

Beth Biller, University of Edinburgh

# Directly Imaged Planetary (or Nearly Planetary) Companions





Data from [exoplanet.eu](http://exoplanet.eu)

# Some Fundamental Characterization Questions

## Physical Properties

What are the atmospheres  
of planets like?

## Architecture

Where do planets live in their  
stellar systems?

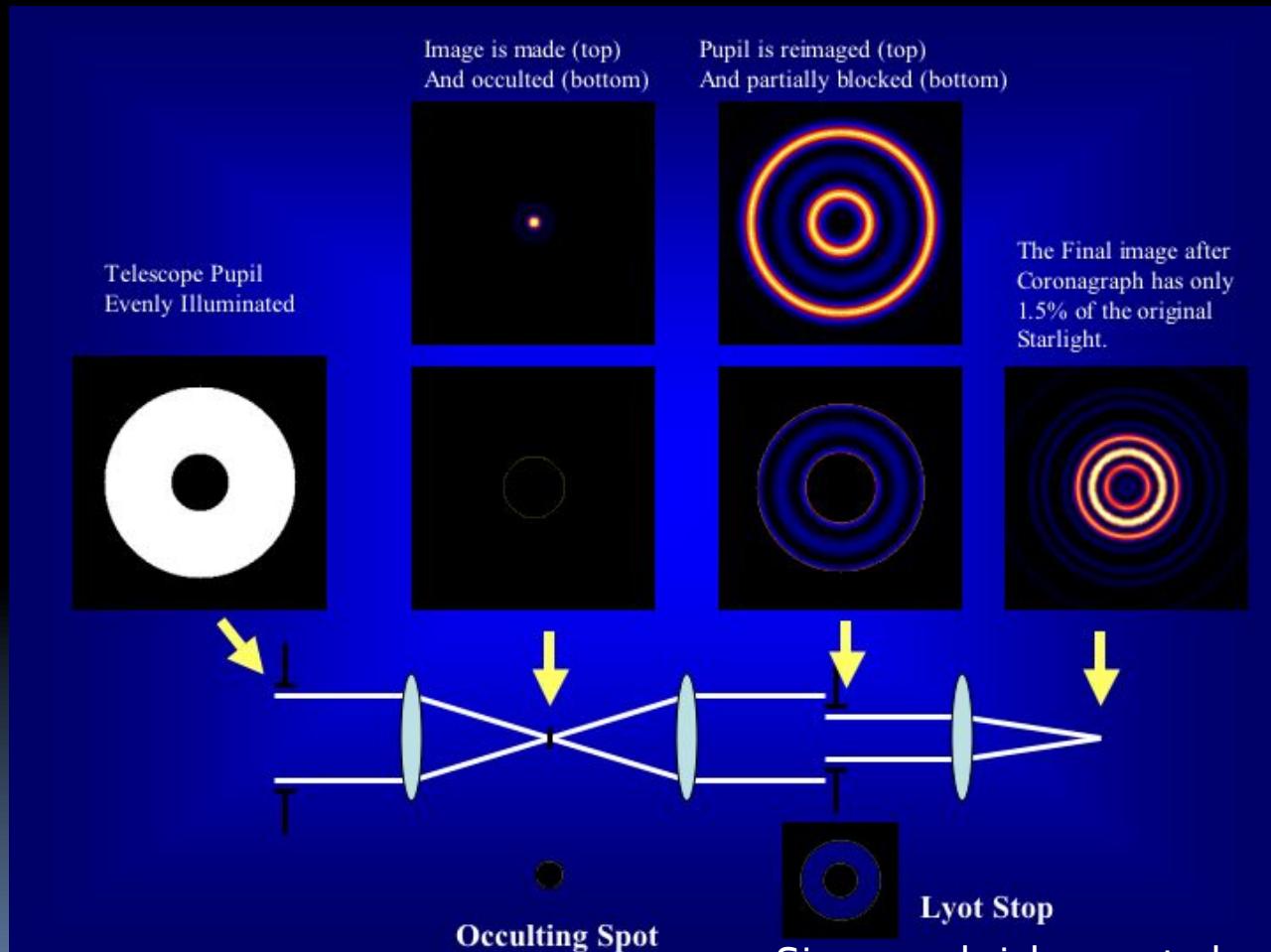
# Technical Aspects of Exoplanet Imaging

# Difficulties with Direct Detection (1)

Huge contrast ratio between planet and star

- >2 Gyr gas giant planets  $>10^8$  fainter than primary.
- Young planets  $\sim 10^{4-7}$  times fainter than primary.

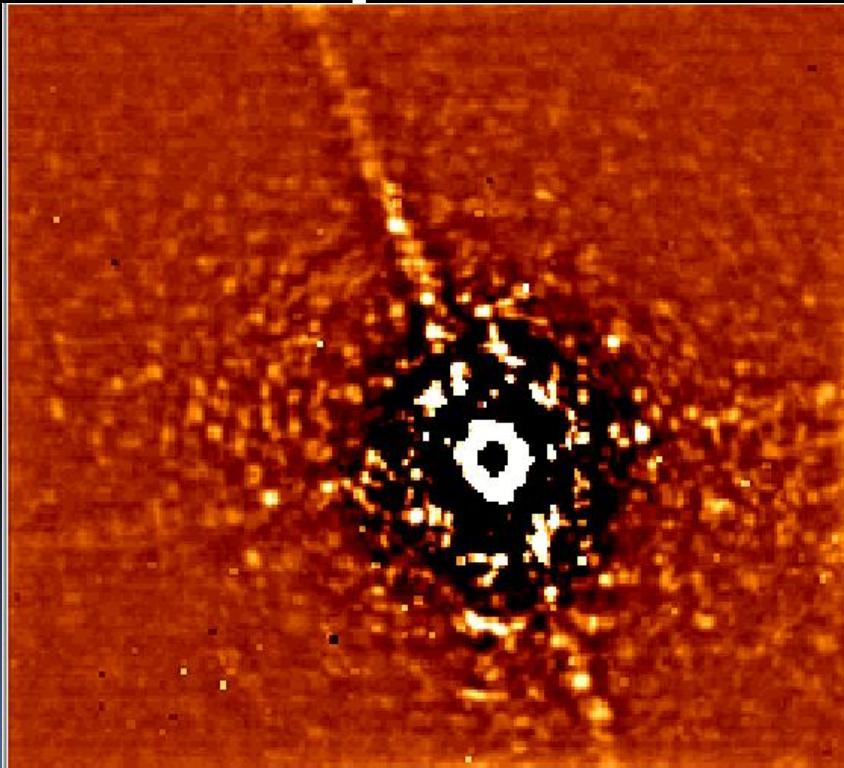
# Coronagraphy



Sivaramakrishnan et al. 2001

# Difficulties with Direct Detection (2)

## Speckle Noise



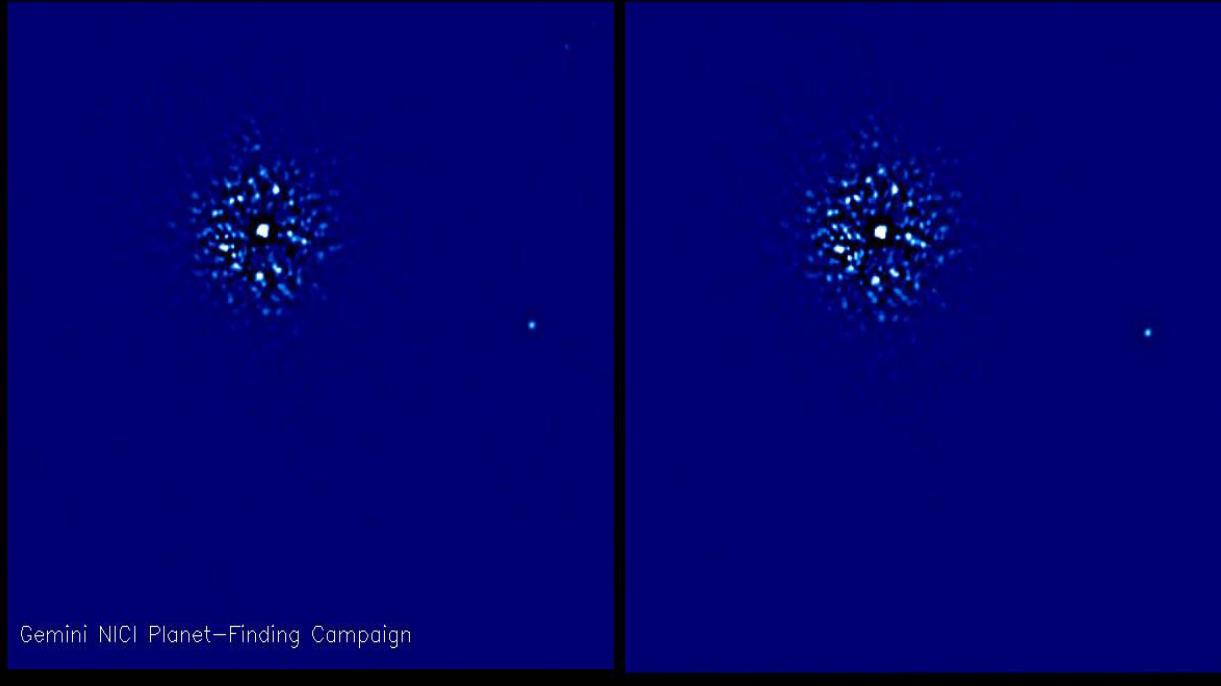
For photon-noise limited data:

$$S/N \sim t_{\text{exp}}^{0.5}$$

For speckle-noise limited data:  
 $S/N$  does not increase with time past a speckle noise floor.

# Angular Differential Imaging

e.g. Schneider et al 2003, Liu 2004, Marois et al 2006, Heinze et al 2008



Rotation on sky decorrelates  
real objects from speckles

# Current Direct Imaging Efforts

# Ongoing or Recently Completed Surveys:

NICI Science Campaign, Biller et al. 2013, Wahhaj et al. 2013, Nielsen et al. 2013, Nielsen et al. in prep

NACO Large Program, Desidera et al. 2014, Chauvin et al. 2014, Vigan et al. in prep

IDPS, Vigan et al. 2012

SEEDS, Brandt et al. 2014, Janson et al. 2013, Carson et al. in prep

PALMS, Bowler et al. 2013

LEECH, Skemer et al. 2013

# Some Fundamental Characterization Questions

## Physical Properties

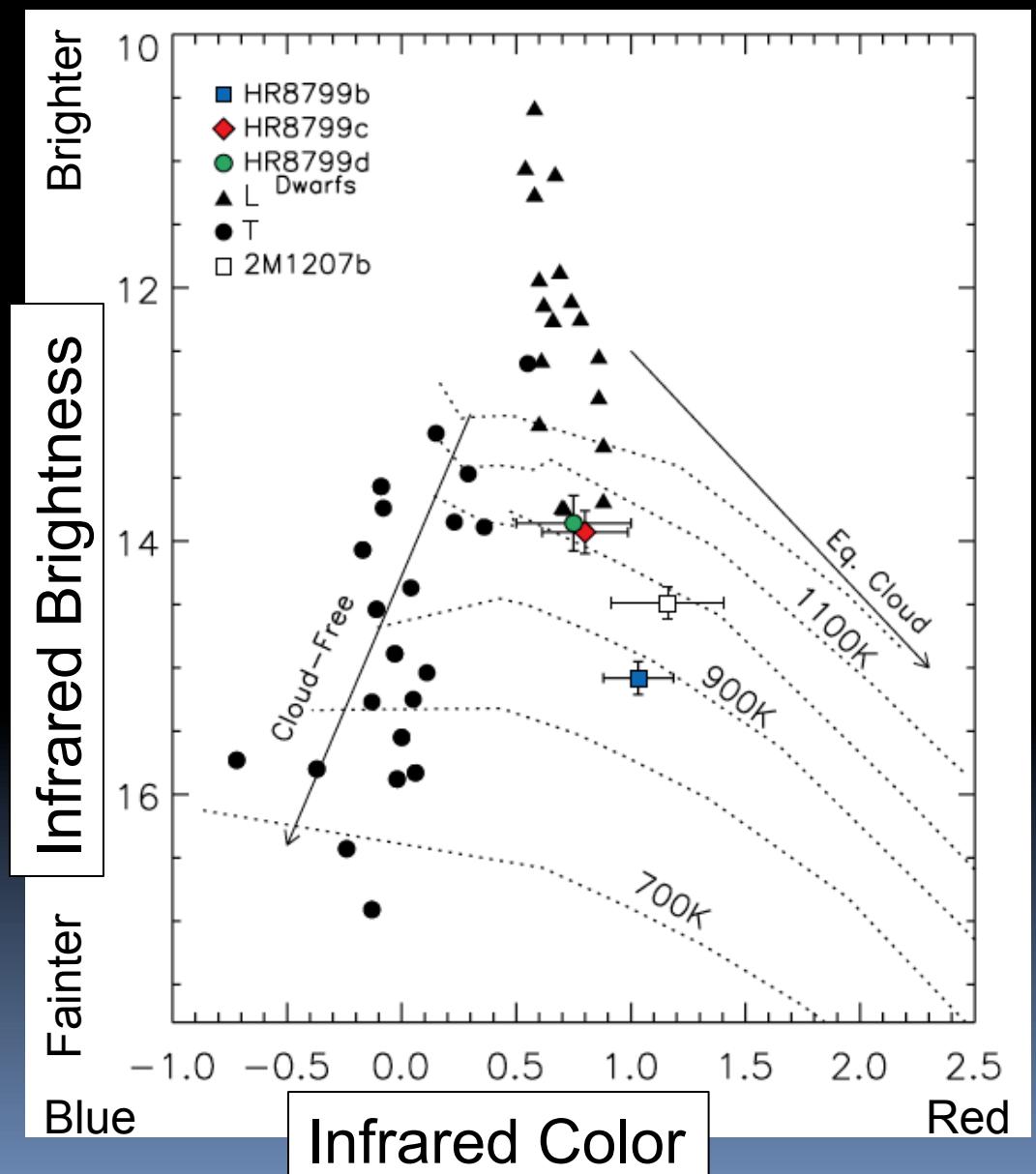
What are the atmospheres  
of planets like?

## Architecture

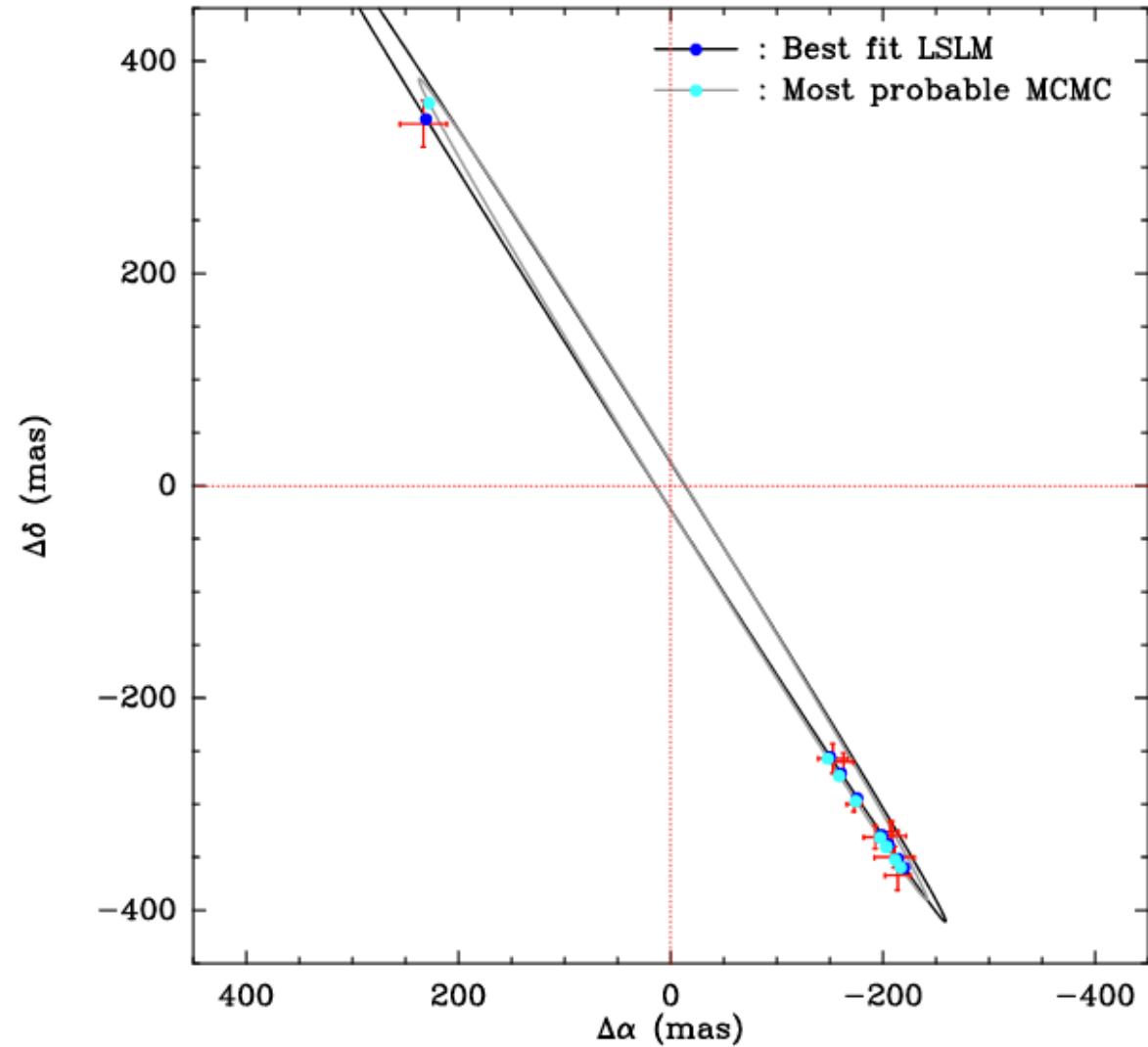
Where do planets live in their  
stellar systems?

# Colors = Atmospheric Information

Red Colors =  
Dusty Clouds



# Towards Accurate Orbits



Orbit for  
Beta Pic b

Chauvin et al. 2012,  
Macintosh et al. 2014,  
Nielsen et al. 2014

Most  
Probable  
Semi-major  
axis:  
**8-9 AU**

See also: poster by A-M. Lagrange

# Some Fundamental Questions of Comparative Exoplanetology

## Physical Properties

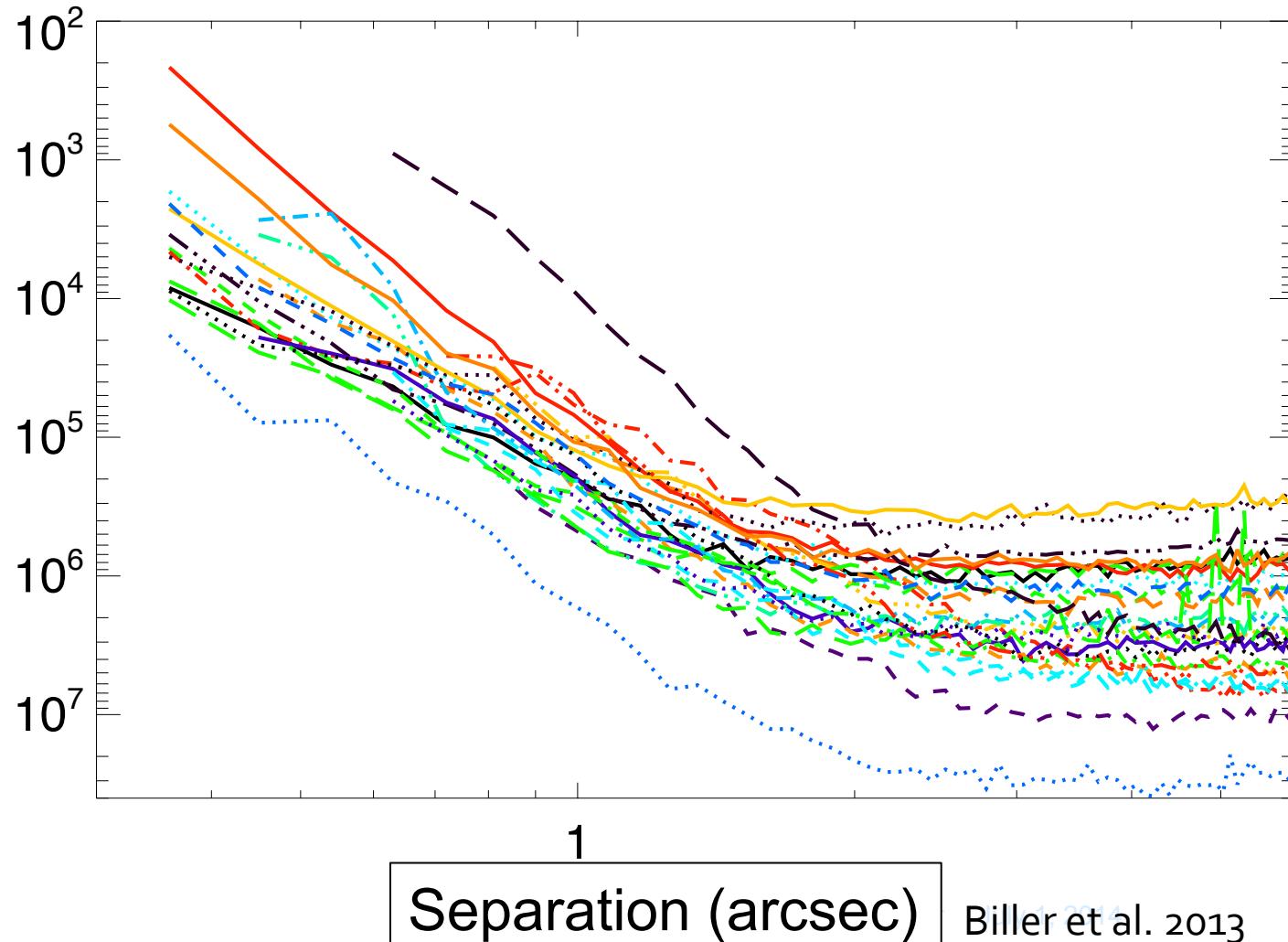
What are the atmospheres  
of planets like?

## Architecture

Where do planets live in their  
stellar systems?

# Excellent contrasts achieved

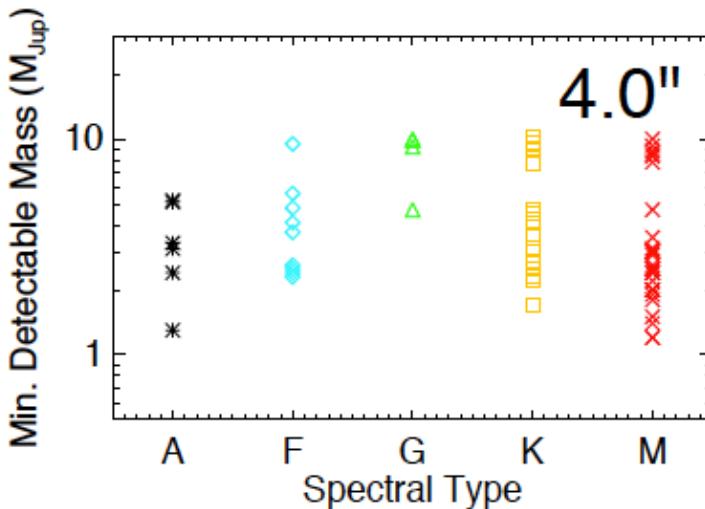
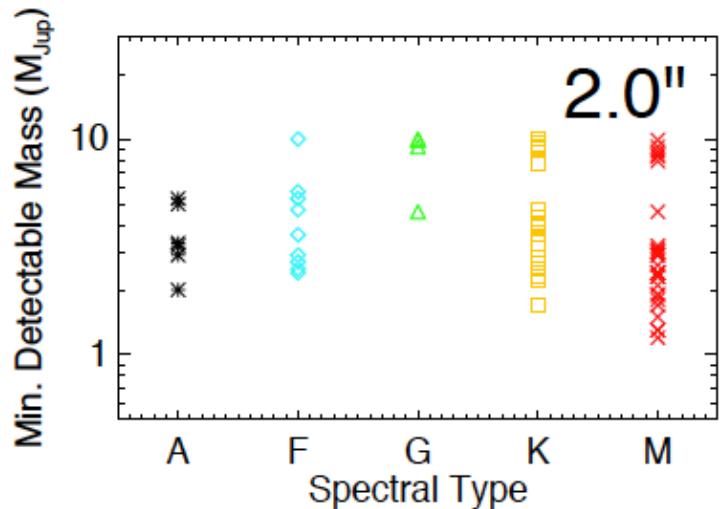
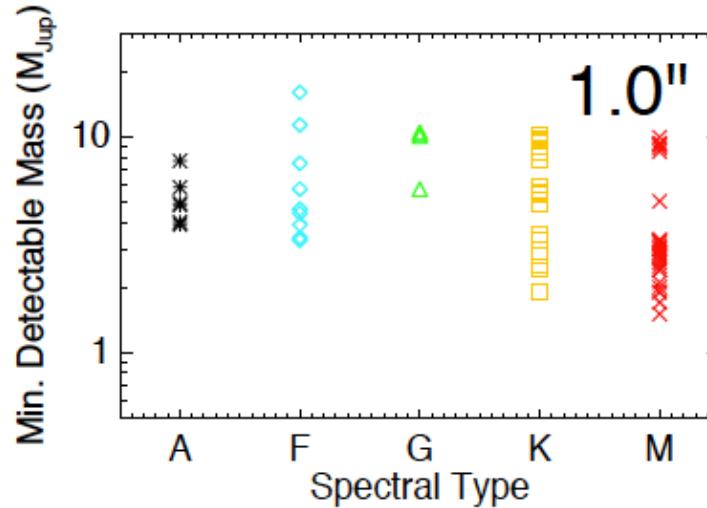
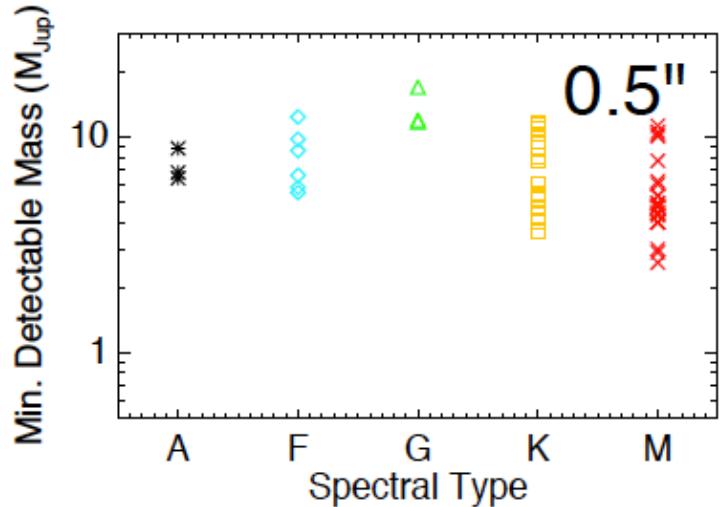
Attainable Star-  
Planet Contrast



# Minimum Detectable Mass ( $M_{\text{Jup}}$ )

# Mass Sensitivity

Biller et al. 2013



Spectral Type

# Strongest Constraint on Planet Fraction to date from 78 NICI Campaign stars:

<8% host 1-20 Mjup  
planets at semi-major  
axes of 10-150 AU  
(95% confidence level, COND models)

# Current State of the Art

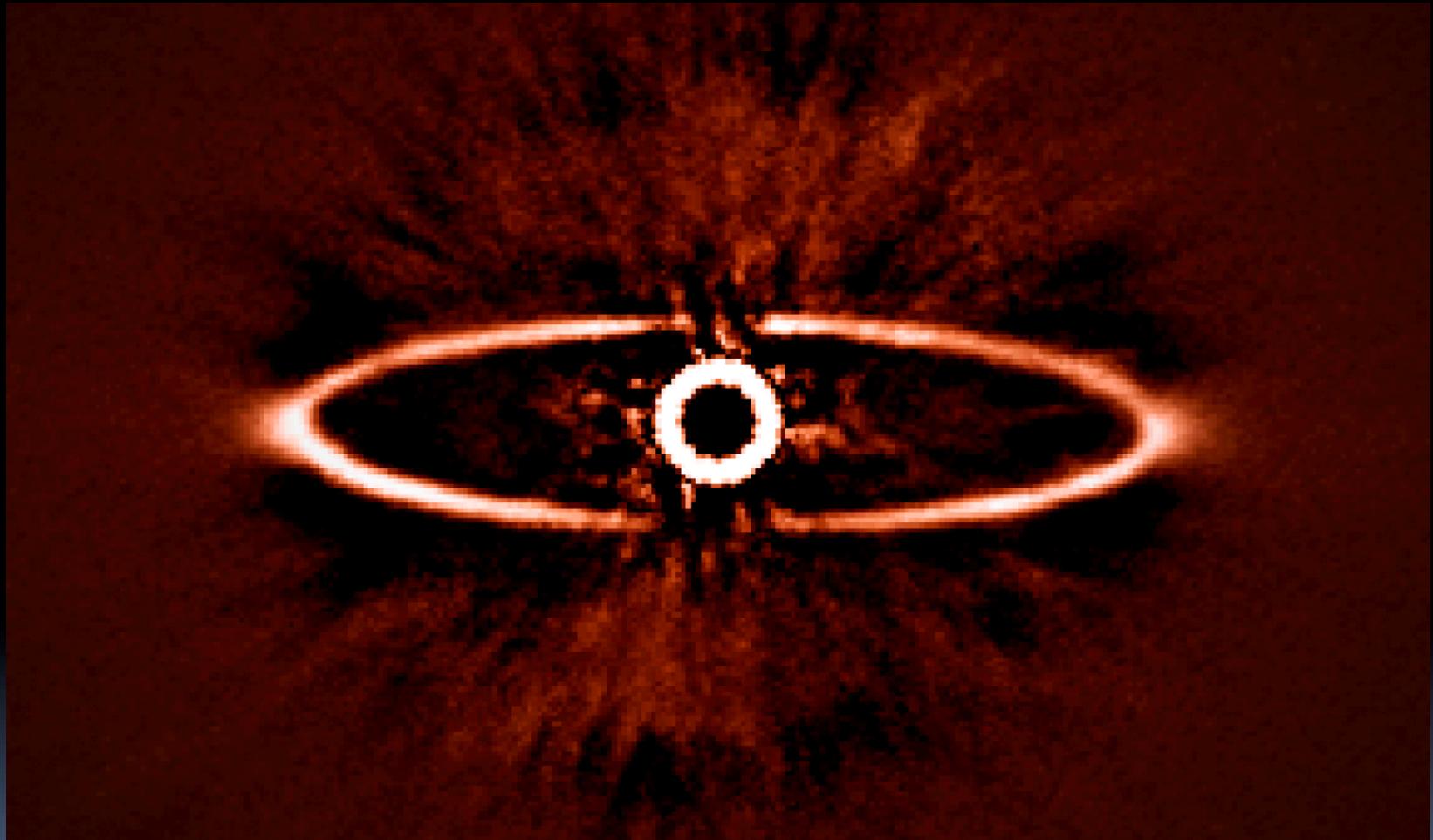
## Physical Properties

Young exoplanets imaged to date have **red colors** indicative of clouds and/or non-equilibrium chemistry.

## Architecture

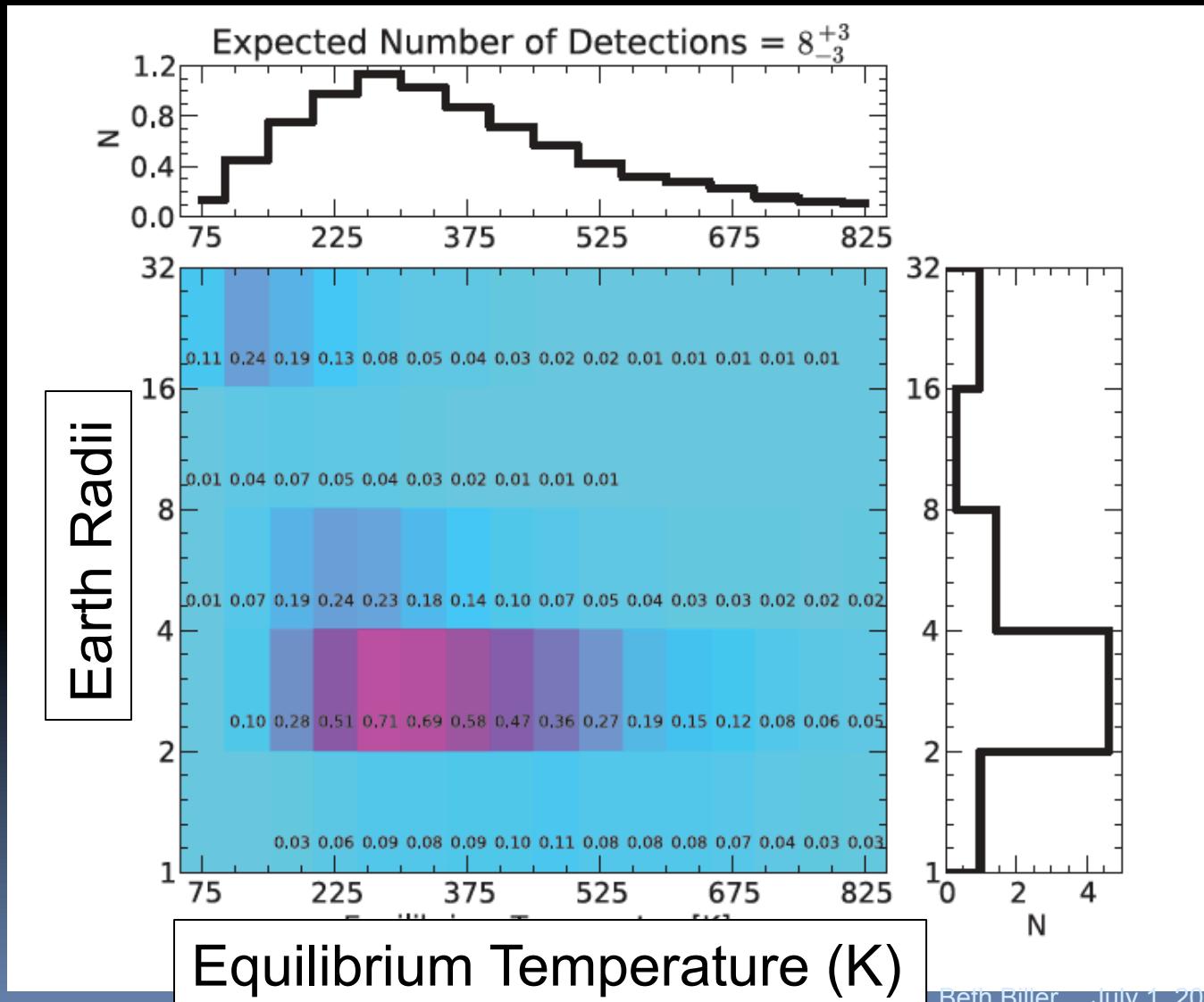
Hot-start gas-giant ( $>4 M_{\text{jup}}$ ) planets are rare at  $>10$  AU.

# First Results with SPHERE

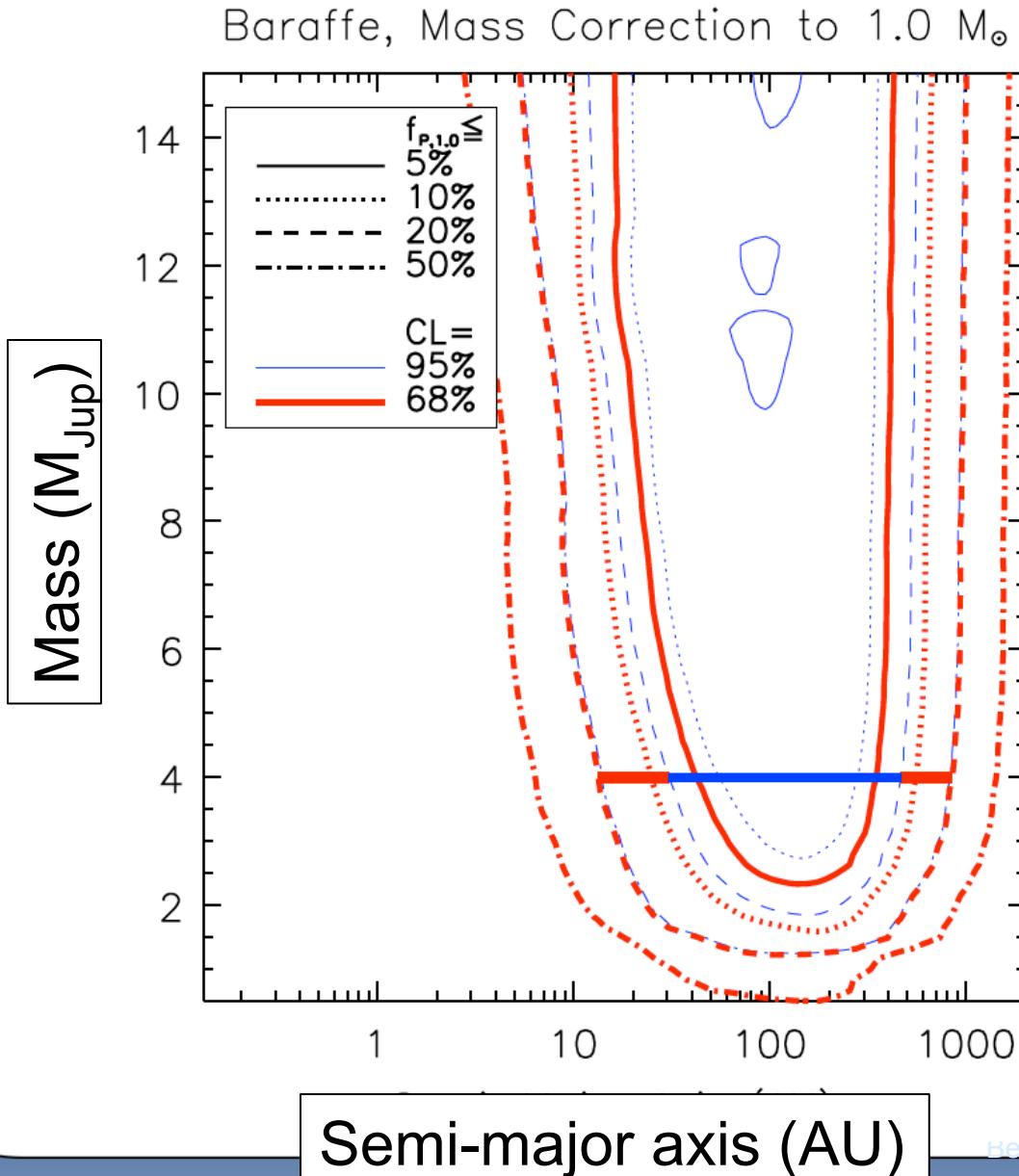


<http://www.eso.org/public/news/eso1417/>

# Direct Imaging of Extrasolar Earths around Nearby M Stars

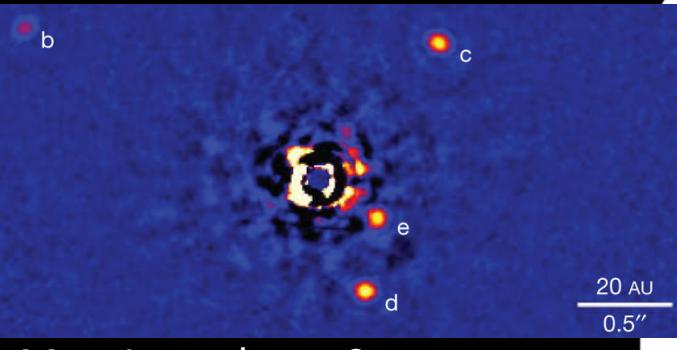


# Earlier Generations of Surveys

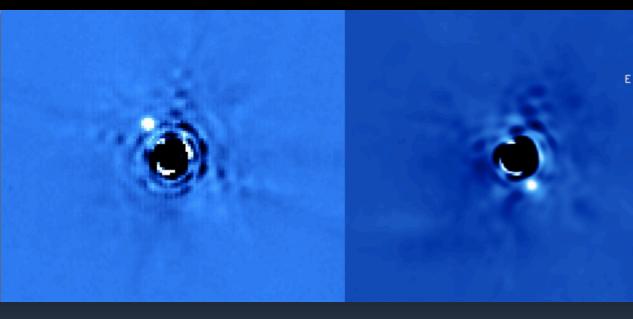


Results from Nielsen and Close 2010, compiling data from 118 stars from Masciadri et al. 2005, Biller et al. 2007, and Lafrenière et al. 2007

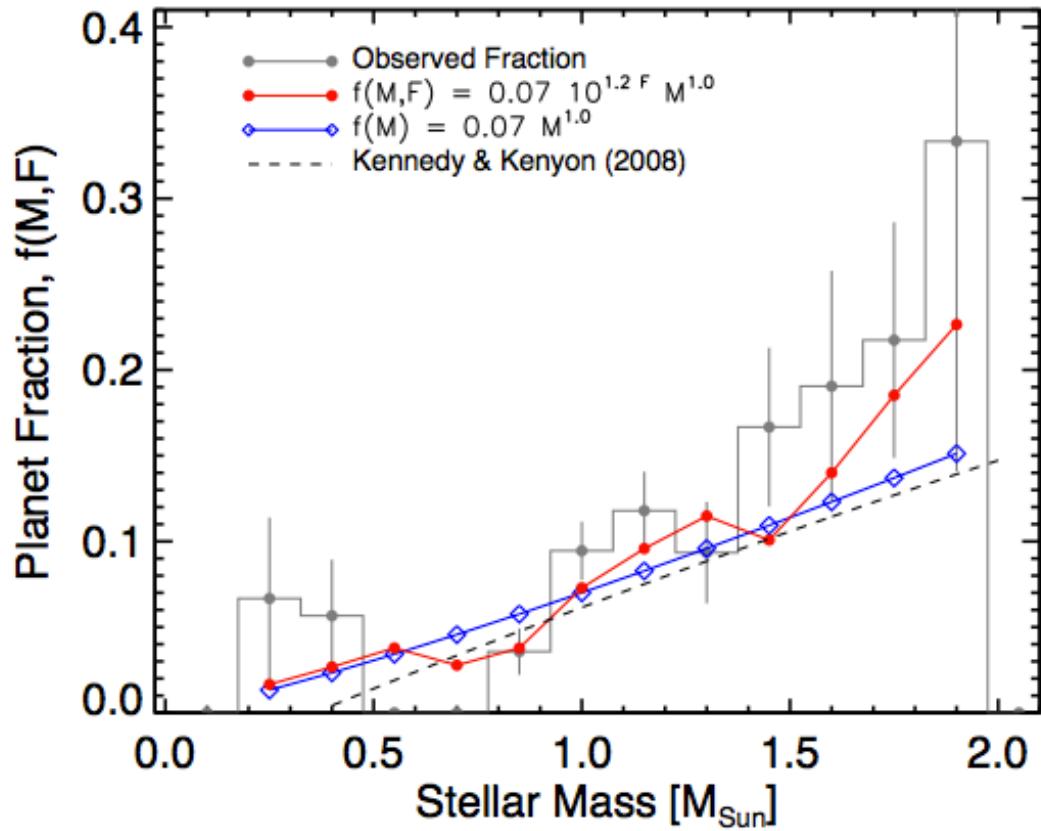
# A Stars – Janson et al. 2011, 2012, Vigan et al. 2012, Nielsen et al. 2013, Carson et al. in prep



Marois et al. 2008, 2010



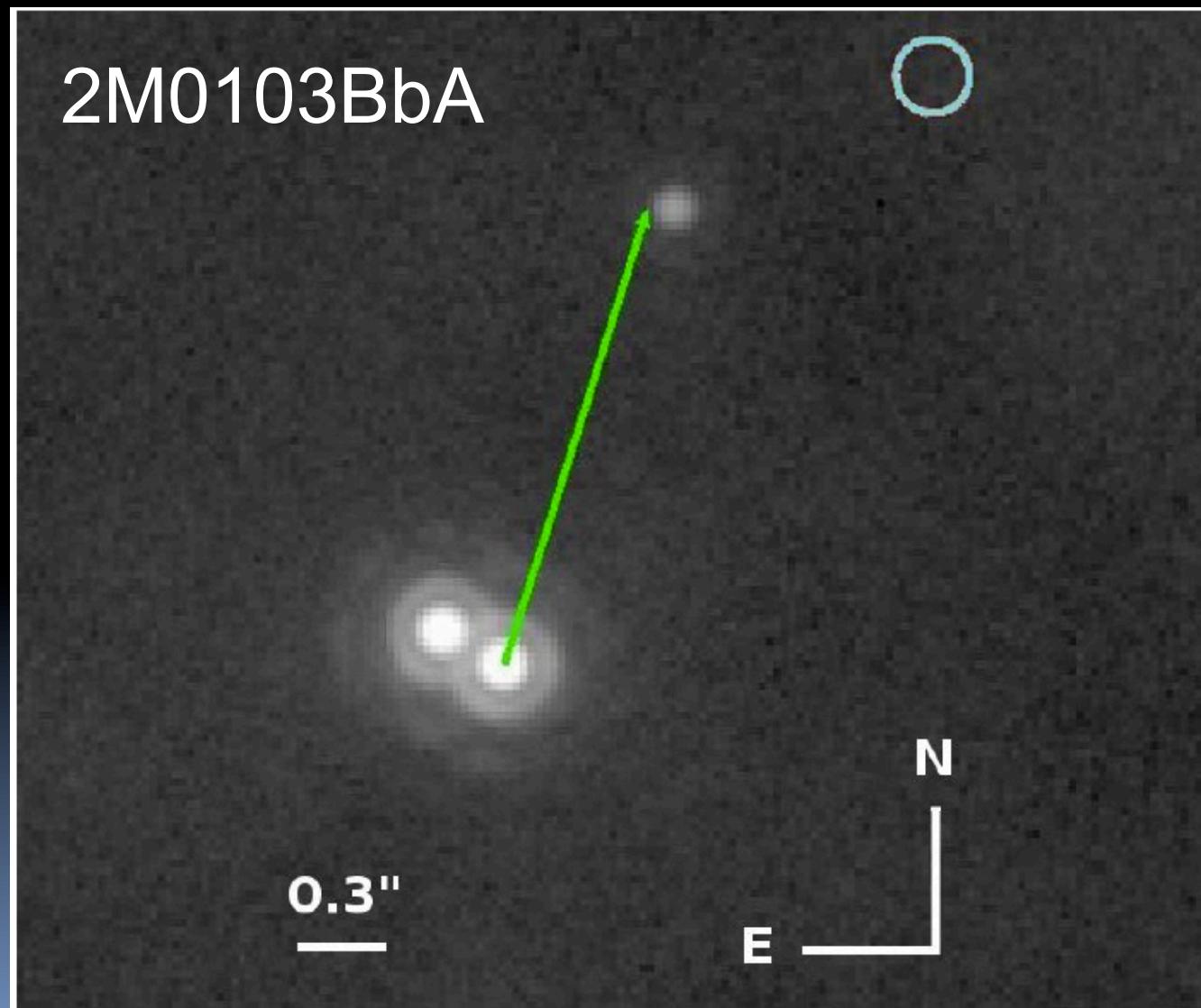
Lagrange et al. 2008, 2010



Johnson et al. 2007 2010

Beth Biller July 1, 2014

# M Stars – Delorme et al. 2012, 2013, Bowler et al. 2012, 2013



**Debris Disk Host Stars** – Wahhaj et al. 2013, Janson et al. 2013

**Moving Group Stars** – Chauvin et al. 2010, Biller et al. 2013, Brandt et al. 2014

**RV Trend Stars** – Crepp et al. 2012a, 2012b, 2013